

Amendments to the Claims:

This listing of claims will replace all prior versions, and listings, of claims in the application:

Listing of Claims:

- 1           1.     (Currently Amended) A linear method for performing head  
2     motion estimation from facial feature data, the method comprising  
3     the steps of:  
4             obtaining a first facial image and detecting a head in said  
5     first image;  
6             detecting position of ~~not more than only~~ four points  $P$  of said  
7     first facial image where  $P = \{p_1, p_2, p_3, p_4\}$ , and  $p_k = (x_k, y_k)$ ;  
8             obtaining a second facial image and detecting a head in said  
9     second image;  
10            detecting position of ~~not more than only~~ four points  $P'$  of  
11     said ~~first~~ second facial image where  $P' = \{p'_1, p'_2, p'_3, p'_4\}$  and  $p'_k = (x'_k, y'_k)$ ;  
12     and  
13            determining the motion of the head represented by a rotation  
14     matrix  $R$  and translation vector  $T$  using said points  $P$  and  $P'$ .

1           2.     (Currently Amended) The linear method of claim 1, wherein  
2 | said only four points  $P$  of said first facial image and said only  
3 four points  $P'$  of said second facial image include locations of  
4 outer corners of each eye and mouth of each respective first and  
5 second facial images.

1           3.     (Original)       The linear method of claim 1, wherein said  
2 head motion estimation is governed according to:

3            $P'_i = RP_i + T$ , where  $R = \begin{bmatrix} r_1^r \\ r_2^r \\ r_3^r \end{bmatrix} = [r_{ij}]_{3 \times 3}$  and  $T = [T_1 \ T_2 \ T_3]^T$  represent camera  
4 rotation and translation respectively, said head pose estimation  
5 being a specific instance of head motion estimation.

1           4.     (Currently amended) A linear method for performing head  
2 motion estimation from facial feature data, the method comprising  
3 the steps of:

4           obtaining a first facial image and detecting a head in said  
5 first image;

6           detecting position of four points  $P$  of said first facial image  
7 where  $P = \{p_1, p_2, p_3, p_4\}$ , and  $p_k = (x_k, y_k)$ ;

8           obtaining a second facial image and detecting a head in said  
9 second image;

10 | detecting position of four points  $P'$  of said ~~first-second~~

11 facial image where  $P' = \{p'_1, p'_2, p'_3, p'_4\}$  and  $p'_k = (x'_k, y'_k)$ ; and,

12 determining the motion of the head represented by a rotation

13 matrix  $R$  and translation vector  $T$  using said points  $P$  and  $P'$ ,

14 wherein said head motion estimation is governed according to:

15  $P'_i = RP_i + T$ , where  $R = \begin{bmatrix} r_1^T \\ r_2^T \\ r_3^T \end{bmatrix} = [r_{ij}]_{3 \times 3}$  and  $T = [T_1 \ T_2 \ T_3]^T$  represent camera

16 rotation and translation respectively, said head pose estimation

17 being a specific instance of head motion estimation, and

18 wherein said head motion estimation is governed according to

19 said rotation matrix  $R$ , said method further comprising the steps

20 of:

21 determining rotation matrix  $R$  that maps points  $P_k$  to  $F_k$  for

22 characterizing a head pose, said points  $F_1, F_2, F_3, F_4$  representing three-

23 dimensional (3-D) coordinates of the respective four points of a

24 reference, frontal view of said facial image, and  $P_k$  is the three-

25 dimensional (3-D) coordinates of an arbitrary point where

26  $P_i = [X_i \ Y_i \ Z_i]^T$ , said mapping governed according to the relation:

27

$$R(P_2 - P_1) \propto [1 \ 0 \ 0]^T$$

28  $R(P_6 - P_5) \propto [0 \ 1 \ 0]^T$

29

30 wherein  $P_5$  and  $P_6$  are midpoints of respective line segments  
 31 connecting points  $P_1P_2$  and  $P_3P_4$  and, line segment connecting points  
 32  $P_1P_2$  is orthogonal to a line segment connecting points  $P_5P_6$ , and  
 33  $\propto$  indicates a proportionality factor.

1 5. (Original) The linear method of claim 4, wherein  
 2 components  $r_1$ ,  $r_2$  and  $r_3$  are computed as:

$$\begin{aligned} & r_2^T (P_2 - P_1) = 0 \\ & r_3^T (P_2 - P_1) = 0 \\ 3 \quad & r_1^T (P_6 - P_5) = 0 \\ & r_3^T (P_6 - P_5) = 0 \end{aligned}$$

1 6. (Original) The linear method of claim 5, wherein  
 2 components  $r_1$ ,  $r_2$  and  $r_3$  are computed as:

$$\begin{aligned} 3 \quad & r_3 = (P_6 - P_5) \times (P_2 - P_1), \\ & r_2 = r_3 \times (P_2 - P_1) \\ 4 \quad & r_1 = r_2 \times r_3 \end{aligned}$$

1 7. (Original) The linear method of claim 4, wherein

$$2 \quad \begin{bmatrix} P_1^T & 0^T & 0^T & 1 & 0 & 0 \\ 0^T & P_2^T & 0^T & 0 & 1 & 0 \\ 0^T & 0^T & P_3^T & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} r_1 \\ r_2 \\ r_3 \\ T \end{bmatrix} = P',$$

3       each point pair yielding 3 equations, whereby at least four  
4       point pairs are necessary to linearly solve for said rotation and  
5       translation.

1       8.     (Original)       The linear method of claim 7, further  
2       comprising the step of: decomposing said rotation matrix  $R$  using  
3       Singular Value Decomposition (SVD) to obtain a form  $R = USV^T$ .

1       9.     (Original)       The linear method of claim 7, further  
2       comprising the step of computing a new rotation matrix according to  
3        $R = UV^T$ .

1       10.    (Original)       A linear method for performing head motion  
2       estimation from facial feature data, the method comprising the  
3       steps of:  
4       obtaining image position of four points  $P_k$  of a facial image;  
5       determining a rotation matrix  $R$  that maps points  $P_k$  to  $F_k$  for  
6       characterizing a head pose, said points  $F_1, F_2, F_3, F_4$  representing  
7       three-dimensional (3-D) coordinates of the respective four points  
8       of a reference, frontal view of said facial image, and  $P_k$  is the

9 three-dimensional (3-D) coordinates of an arbitrary point where

10  $P_i = [X_i \ Y_i \ Z_i]^T$ , said mapping governed according to the relation:

11

$$R(P_2 - P_1) \propto [1 \ 0 \ 0]^T$$

12

$$R(P_6 - P_5) \propto [0 \ 1 \ 0]^T$$

13

14 wherein  $P_5$  and  $P_6$  are midpoints of respective line segments  
 15 connecting points  $P_1P_2$  and  $P_3P_4$  and, line segment connecting points  
 16  $P_1P_2$  is orthogonal to a line segment connecting points  $P_5P_6$ , and  
 17  $\propto$  indicates a proportionality factor.

1 11. (Original) The linear method of claim 10, wherein  
 2 components  $r_1$ ,  $r_2$  and  $r_3$  are computed as:

$$r_2^T(P_2 - P_1) = 0$$

3

$$r_3^T(P_2 - P_1) = 0$$

$$r_1^T(P_6 - P_5) = 0$$

$$r_3^T(P_6 - P_5) = 0$$

1 12. (Original) The linear method of claim 11, wherein  
 2 components  $r_1$ ,  $r_2$  and  $r_3$  are computed as:

3

$$r_3 = (P_6 - P_5) \times (P_2 - P_1),$$

$$r_2 = r_3 \times (P_2 - P_1)$$

4

$$r_1 = r_2 \times r_3$$

1           13. (Original)       The linear method of claim 12, wherein a  
2 motion of head points is represented according to  $P'_i = RP_i + T$

$$R = \begin{bmatrix} r_1^T \\ r_2^T \\ r_3^T \end{bmatrix} = [r_{ij}]_{3 \times 3}$$

3           where  $R$  represents image rotation,  $T = [T_1 \ T_2 \ T_3]^T$   
4 represents translation, and  $P'_i$  denotes a 3-D image position of four  
5 points  $P_k$  of another facial image

1           14. (Original)       The linear method of claim 13, wherein

$$2 \quad \begin{bmatrix} P_i^T & 0^T & 0^T & 1 & 0 & 0 \\ 0^T & P_i^T & 0^T & 0 & 1 & 0 \\ 0^T & 0^T & P_i^T & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} r_1 \\ r_2 \\ r_3 \\ T \end{bmatrix} = P'_i,$$

3           each point pair yielding 3 equations, whereby at least four  
4 point pairs are necessary to linearly solve for said rotation and  
5 translation.

1           15. (Original)       The linear method of claim 14, further  
2 comprising the step of: decomposing said rotation matrix  $R$  using  
3 Singular Value Decomposition (SVD) to obtain a form  $R = USV^T$ .

1           16. (Original)           The linear method of claim 15, further  
2   comprising the step of computing a new rotation matrix according to  
3    $R = UV^T$ .

1           17. (Currently Amended) A program storage device readable by  
2   machine, tangible embodying a program of instructions executable by  
3   the machine to perform method steps for performing head motion  
4   estimation from facial feature data, the method comprising the  
5   steps of:  
6           obtaining a first facial image and detecting a head in said  
7   first image;  
8           detecting position of ~~not more than~~ only four points P of said  
9   first facial image where  $P = \{p_1, p_2, p_3, p_4\}$ , and  $p_k = (x_k, y_k)$ ;  
10          obtaining a second facial image and detecting a head in said  
11   second image;  
12          detecting position of ~~not more than~~ only four points P' of  
13   said ~~first~~ second facial image where  $P' = \{p'_1, p'_2, p'_3, p'_4\}$  and  $p'_k = (x'_k, y'_k)$ ;  
14   and,  
15          determining the motion of the head represented by a rotation  
16   matrix R and translation vector T using said points P and P'.



1        18. (Currently amended) The program storage device readable  
 2 | by machine as claimed in claim 17, wherein said only four points P  
 3 | of said first facial image and only four points P' of said second  
 4 | facial image include locations of outer corners of each eye and  
 5 | mouth of each respective first and second facial image.

1        19. (Original)        The program storage device readable by  
 2 machine as claimed in claim 17, wherein said head motion estimation  
 3 is governed according to:

4        
$$P'_i = RP_i + T, \quad \text{where} \quad R = \begin{bmatrix} r_1^T \\ r_2^T \\ r_3^T \end{bmatrix} = [r_{ij}]_{3 \times 3} \quad \text{and} \quad T = [T_1 \ T_2 \ T_3]^T \quad \text{represent}$$
  
 5 camera rotation and translation respectively, said head pose  
 6 estimation being a specific instance of head motion estimation.

1        20. (Previously presented)        A program storage device  
 2 readable by machine, tangible embodying a program of instructions  
 3 executable by the machine to perform method steps for performing  
 4 head motion estimation from facial feature data, the method  
 5 comprising the steps of:  
 6        obtaining a first facial image and detecting a head in said  
 7 first image;

8 detecting position of four points  $P$  of said first facial image  
 9 where  $P = \{P_1, P_2, P_3, P_4\}$ , and  $P_k = (x_k, y_k)$ ;  
 10 obtaining a second facial image and detecting a head in said  
 11 second image;  
 12 detecting position of four points  $P'$  of said ~~first~~second  
 13 facial image where  $P' = \{P'_1, P'_2, P'_3, P'_4\}$  and  $P'_k = (x'_k, y'_k)$ ; and  
 14 determining the motion of the head represented by a rotation  
 15 matrix  $R$  and translation vector  $T$  using said points  $P$  and  $P'$ ,  
 16 wherein said head motion estimation is governed according to:

$$R = \begin{bmatrix} r_1^T \\ r_2^T \\ r_3^T \end{bmatrix} = [r_{ij}]_{3 \times 3}$$

17  $P'_i = RP_i + T$ , where and  $T = [T_1 \ T_2 \ T_3]^T$  represent  
 18 camera rotation and translation respectively, said head pose  
 19 estimation being a specific instance of head motion estimation, and  
 20 wherein said head pose estimation is governed according to  
 21 said rotation matrix  $R$ , said method further comprising the steps  
 22 of:

23 determining rotation matrix  $R$  that maps points  $P_k$  to  $F_k$  for  
 24 characterizing a head pose, said points  $F_1, F_2, F_3, F_4$  representing three-  
 25 dimensional (3-D) coordinates of the respective four points of a  
 26 reference, frontal view of said facial image, and  $P_k$  is the three-

27 dimensional (3-D) coordinates of an arbitrary point where  
28  $P_i = [X_i \ Y_i \ Z_i]^T$ , said mapping governed according to the relation:

29

$$\begin{aligned} R(P_2 - P_1) &\propto [1 \ 0 \ 0]^T \\ R(P_6 - P_5) &\propto [0 \ 1 \ 0]^T \end{aligned}$$

30

31

32 wherein  $P_5$  and  $P_6$  are midpoints of respective line segments  
33 connecting points  $P_1P_2$  and  $P_3P_4$  and, line segment connecting points  
34  $P_1P_2$  is orthogonal to a line segment connecting points  $P_5P_6$ , and  
35  $\propto$  indicates a proportionality factor.

1 21. (Previously presented) The program storage device  
2 readable by machine as claimed in claim 20, wherein components  $r_1$ ,  
3  $r_2$  and  $r_3$  are computed as:

$$\begin{aligned} r_2^T (P_2 - P_1) &= 0 \\ r_3^T (P_2 - P_1) &= 0 \\ r_1^T (P_6 - P_5) &= 0 \\ 4 \quad r_3^T (P_6 - P_5) &= 0 \end{aligned}$$

1 22. (Previously presented) The program storage device  
2 readable by machine as claimed in claim 20, wherein components  $r_1$ ,  
3  $r_2$  and  $r_3$  are computed as:

$$4 \quad \mathbf{r}_3 = (\mathbf{P}_6 - \mathbf{P}_5) \times (\mathbf{P}_2 - \mathbf{P}_1),$$

$$\mathbf{r}_2 = \mathbf{r}_3 \times (\mathbf{P}_2 - \mathbf{P}_1)$$

$$5 \quad \mathbf{r}_1 = \mathbf{r}_2 \times \mathbf{r}_3$$

1        23. (Previously presented)    The program storage device  
2    readable by machine as claimed in claim 20, wherein

$$3 \quad \begin{bmatrix} \mathbf{P}_i^T & \mathbf{0}^T & \mathbf{0}^T & 1 & 0 & 0 \\ \mathbf{0}^T & \mathbf{P}_i^T & \mathbf{0}^T & 0 & 1 & 0 \\ \mathbf{0}^T & \mathbf{0}^T & \mathbf{P}_i^T & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \mathbf{r}_1 \\ \mathbf{r}_2 \\ \mathbf{r}_3 \\ \mathbf{T} \end{bmatrix} = \mathbf{P}_i'$$

4        each point pair yielding 3 equations, whereby at least four  
5    point pairs are necessary to linearly solve for said rotation and  
6    translation.

24. (Previously presented)    The program storage device  
readable by machine as claimed in claim 23, further comprising the  
steps of decomposing said rotation matrix  $R$  using Singular Value  
Decomposition (SVD) to obtain a form  $R = USV^T$ .

25. (Previously presented)    The program storage device  
readable by machine as claimed in claim 23, further comprising the  
steps of computing a new rotation matrix according to  $R = UV^T$ .